Moderate hypoxia or hyperoxia affect fillet yield and the proportion of red muscle in rainbow trout

by

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ABSTRACT. - Despite the common use of oxygen supplementation in fish farms to maintain oxygen level around normoxia, the long-term effects of this practice on zootechnical performance has been extensively described but there is a lack of data concerning fish quality. Rainbow trout were reared in freshwater, from 12 g to 400 g, at three oxygen levels (76 ± 4, 98 ± 14 and 117 ± 12% saturation, mean ± standard deviation) in order to assess the influence of long-term oxygen exposure on fish carcass quality traits in 2 m^3 tanks. At the end of the 18 weeks experiment, no effect of oxygen level on fish weight and morphometric traits (condition factor, fish height and width) was observed. No significant effect of oxygen level was measured on carcass yield, viscero-somatic index, nor on hepato-somatic index. In fish reared at 117% oxygen saturation, fillet yields was higher than in the 76% group (+ 2.6%) and concomitantly there was a higher development of red muscle (+ 8.4%). Thus oxygen level was shown to affect carcass quality, but the biological basis of this effect remains to be elucidated.

RÉSUMÉ. - Des niveaux d'oxygène proches de la normoxie modifient les rendements en filets et la proportion de muscle rouge chez la truite arc-en-ciel.

L'oxygénation artificielle de l'eau est une pratique courante en salmoniculture mais, si ses effets à long terme sur les performances zootechniques des animaux sont assez bien documentés, l'impact sur la qualité des carcasses reste à évaluer. Des truites arc-en-ciel ont été élevées en eau douce, de 12 g à 400 g, à trois niveaux d'oxygène (76 ± 4, 98 ± 14 et 117 ± 12% de la saturation, moyenne ± écart-type) pour déterminer les effets à long terme des niveaux d'oxygène sur la qualité des carcasses (morphologie, rendements) dans des conditions piscicoles. Ces traitements n'ont pas induit d'effet à long terme sur le poids ni sur les paramètres morphométriques (coefficient de condition, hauteur et épaisseur) des poissons prélevés au terme de l'expérience. Aucun effet significatif du niveau d'oxygène n'a été mesuré sur le rendement en carcasse, l'indice viscéro-somatique, ni sur l'indice hépato-somatique. Les rendements en filets plus forts chez les poissons élevés à 117% de saturation en oxygène (+ 2,6% par rapport au lot élevé à 76%, $p < 0,05$) sont associés à un développement plus important du muscle rouge (+ 8,4%, $p < 0,001$). Il est montré que les niveaux d'oxygène affectent la qualité des carcasses mais les bases biologiques qui sous-tendent ces effets restent à explorer.

Key words. - Salmonidae - *Onchorhynchus mykiss* - Rainbow trout - Growth - Oxygen level - Red muscle - Fillet yields.

The oxygen demands of fish mainly depends on species, activity and fish size, and fish have to adapt to fluctuations in environmental factors, such as temperature, salinity and water quality, that affect oxygen concentration. Sensitivity to oxygen is very dependent on species. Thus, lethal concentration of oxygen in water vary from 0.5 to 3 mg/l depending on species and was estimated around 2-3 mg/l for salmonids (Dean and Richardson, 1999; Landman *et al.*, 2005).

Above lethal oxygen concentration, fish are able to survive but are submitted to severe hypoxia up to a critical value of oxygen concentration, also dependent on species and estimated around 4-6 mg/l for salmonids. Severe hypoxia was shown to have an impact on fish biology leading to a metabolic acidosis (Claireaux *et al.*, 1988), an activation of stress physiological response and anaerobic metabolism, and depression of energy status (van Raaij *et al.*, 1994; 1996).

Fish are able to adapt to limited hypoxia by modifying their behaviour and metabolism (Dunn and Hochachka, 1987; Person-Le Ruyet *et al.*, 2003). Changes in respiratory and circulatory systems were measured such as modification of heart and ventilation rates, arterial O_2 tension, or haemoglobin oxygen affinity (Boutilier *et al.*, 1988; Riera *et al.*, 1993; Borch *et al.*, 1993; Mckenzie *et al.*, 2004). These adaptative adjustments are dose- and time-dependant and are affected by fish species and size (Smit and Hattingh, 1981; Pichavant *et al.*, 2003).

The effect of oxygen on fish growth has been shown to be almost linear for oxygen values under a threshold oxygen concentration, estimated around 6-8 mg/l for salmonids (Pedersen, 1987), supporting the "Limiting Factor" concept

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(Brett, 1979). A lower growth rate, due to hypoxia was demonstrated for many species including salmonids (Pedersen, 1987; Dabrowski *et al.*, 2004) and marine fish species (Thetmeyer *et al.*, 1999; Pichavant *et al.*, 2000; 2001; Foss and Imsland, 2002; Person-Le Ruyet *et al.*, 2003). Limited growth due to hypoxia was clearly demonstrated to be related to a lower food intake and most often to a lower food conversion efficiency (Pedersen, 1987; Thetmeyer *et al.*, 1999; Pichavant *et al.*, 2000; 2001; Person-Le Ruyet *et al.*, 2003). For oxygen concentration comprised between the threshold concentration and normoxia (> 8mg/l), no effect of oxygen level on fish growth was observed (Edsall and Smith, 1990; Caldwell and Hinshaw, 1994).

Some effects of limited hyperoxia (up to 250% saturation) have also been reported. The most common effect is a change in blood composition (haemoglobin content and saturation, hematocrit) which can be observed or not, depending on species and the level of hyperoxia (Edsall and Smith, 1990; Jewett *et al.*, 1991; Caldwell and Hinshaw, 1994; Person-Le Ruyet *et al.*, 2002). Limited hyperoxia was shown to have generally no effect on fish growth and food conversion (Edsall and Smith, 1990; Doulos and Kindschi, 1990; Jewett *et al.*, 1991; Caldwell and Hinshaw, 1994; Ritola *et al.*, 2002; Person-Le Ruyet *et al.*, 2002). However, a recent study reported a positive long-term effect of hyperoxia (180% oxygen saturation) on the growth of 2 g juvenile rainbow trout (Dabrowski *et al.*, 2004).

At very high level of oxygen concentration (more than 300% of saturation), a toxic effect may be observed in salmonids with modification of acid-base balance (Hobe *et al.*, 1984), anemia (Lane *et al.*, 1991) and lethality when hyperoxia is combined with high pressure conditions (Sebert *et al.*, 1984) but no toxic effect was observed in many fish species (Person-Le Ruyet *et al.*, 2002).

The use of artificial oxygenation is a common practice in fish farms to avoid any deficiency of natural supplies, which could be deleterious for fish. This leads to a variable dissolved oxygen content in the water with values from 80% saturation and up to 200% at the entry of fish farm. Despite its common use, no study has reported the effects of oxygen values close to normoxia, applied throughout the rearing period, and the consequences of such a practice on fish carcass quality has never been described even though this is a great concern for fish farmer. Nevertheless, acute and chronic hypoxia was shown to affect both red and white muscles metabolism in tench and rainbow trout (Johnston, 1975; Johnston and Bernard, 1982) but in these studies a possible effect on muscle mass has not been reported. Adaptation to different oxygen levels may however change total muscle mass, with consequences for fish morphology, or may affect the proportion of white (glycolytic) and red (oxidative) muscles.

The aim of this study was to determine whether the long-term exposure to a range of oxygen concentration (76, 98 and 117% saturation in mean), showed to have no effect on growth performance in different species, throughout the rearing period, had an impact on fish morphology and carcass quality indices (carcass and fillet yields, relative proportion of muscle types) at pan size.

MATERIAL AND METHODS

Fish rearing conditions and experimental design

The experiment was conducted at the SEMII facilities (Station expérimentale mixte Ifremer-INRA, Sizun, Finistère, France). Rainbow trout (*Oncorhynchus mykiss*), from the INRA autumnal spawning strain, were reared in the same 200 l fibre-glass tank supplied with spring water at constant temperature (11 ± 0.5°C) and oxygen saturation level, up to the beginning of the experiment.

At 12 g mean body weight, trout were randomly allocated to groups of 290 fish, into nine 2 m^3 fibre-glass tanks, supplied with water from the lake of Drennec aerated with a U tube providing 100% oxygen saturation and a limited daily temperature variation (+ 0.5°C). Three levels of oxygen saturation, 80%, 100% and 120%, were applied to the experimental tanks (3 replicates per treatment) by adding to the main water supply (up to 3600 l $hour^{-1}$) increasing quantities of over-oxygenated water (250% oxygen saturation) provided by a jet platform (Aquavi, Aquinove®, France). The dissolved oxygen concentration in the experimental tanks was measured with an oximeter (Oxi 323, WTW) and adjusted three times a week. The pipes were directed to the centre of the tank, in order to limit variations in current between the tanks. The daily average total ammonia nitrogen (TAN) concentration calculated from the feed intake and the water flow, according to Cho and Kaushik (1990) and Papatryphon *et al.* (2005), remained under 0.4 $mg.l^{-1}$ throughout the experiment. The amount of feed distributed, continuously by belt-feeders, was calculated each week according a table and using a growth model (Muller-Feuga A., 1990). The mean fish weight was assessed every three weeks, by weighing a sample (about 1/4 of the total number) of fish in each tank.

Fish were first acclimated for 1 month to the experimental conditions then the experiment was conducted for 18 weeks before slaughtering.

Slaughter procedure

Fish were fasted for 48 h before slaughtering and anaesthetized with eugenol solution (0.5 ml/l of 10% eugenol in 95% ethanol) prior to weighing to limit sampling stress, then bled by gill arch section in the anaesthetic bath.

Measurements, index calculation and yield determination

For 16 fish per tank (48 per treatment), body weight (BW in g) and the following morphometric traits were measured immediately after death: fork length (L in mm), height of the head (Hh in mm), body height and width at the anterior edge of the dorsal fin (Hd and Wd in mm), and body height and width behind the adipose fin (Ha and Wa in mm). Condition factor ($K = BW/L^3$), viscero-somatic index (VSI = viscera weight/BW), carcass yield (carcass weight/BW), and hepato-somatic index (HIS = liver weight/BW) were calculated.

The Torry Fish Fat Meter® (Distell Industries Ltd, Scotland) was used to estimate the intra-muscular lipid content (Douirin *et al.*, 1998). Fish were first wiped with paper tissue to remove excess water and mucus. A single location measurement was conducted on each fish by applying the instrument firmly to the dorsal musculature, parallel to the lateral line, between the head and the dorsal fin of the left fillet.

Eight fish per tank (24 per treatment) were hand-filleted by the same person. Fillet yields were estimated by weighing the raw right fillet (F), dressed fillet (DF) and dressed and skinned fillet (DSF). Three indices were calculated: fillet yield (FY = fillet weight/BW), dressed fillet yield (DFY = dressed fillet weight/BW) and dressed and skinned fillet yield (DSFY = dressed and skinned fillet weight/BW). The same indices were also calculated relative to carcass weight (CW): fillet yield (carcass) (Fyc = fillet weight/CW), dressed fillet yield (carcass) (DFYc = dressed fillet weight/CW) and dressed and skinned fillet yield (carcass) (DSFYc = dressed and skinned fillet weight/CW). Fillet yield values were doubled to obtain the index corresponding to two fillets.

Muscle histological analysis

Muscle samples were taken immediately after death from the left side of the fish, just beneath the adipose fin where red muscle is the most abundant. They were fixed in Carnoy fixative (absolute ethanol, chloroform, acetic acid, 6:3:1) for 24 h at 4°C, dehydrated by immersion in successive alcohol and alcohol/butanol solutions and finally embedded in paraffin. Sections (10 µm) were then cut and stained with Sirius Red and Fast Green 0.1% in saturated picric acid (Lopez-De Leon and Rojkind, 1985).

The maximum red muscle width was measured at the level of the lateral line using Visilog 5.4 for Windows. When red muscle was separated into two myomeres, the value retained was the sum of the width of the two myomeres, excluding interstitial connective and adipose tissues. Considering that the main contribution in fish width was due to muscle mass (white and red muscles), the proportion of red muscle width, an estimation of the relative abundance of white and red muscle, was calculated as follows: proportion red muscle width (%) = (2 x red muscle width/fish body width) x 100.

Statistical analysis

All results are expressed as mean ± standard deviation. A one-way ANOVA was used to test the differences between the three oxygen levels measured (53 measurements x 3 replicates) and the effects of the oxygen levels on fish growth at different time of the experiment (3 replicates). A one-way ANOVA procedure was also used to test the effects of oxygen level (Statistica for Windows) on the parameters measured at the end of the experiment. Significant ANOVA was followed by a multiple comparison test (Newman-Keuls test). Level of significance was taken as $p < 0.05$. The number of fish measured for each parameter is specified in the table captions.

RESULTS

Oxygen and temperature values

The mean values of dissolved oxygen concentrations of the 3 experimental groups measured throughout the experiment were: 75.9% ± 4.0 (CV = 5.2%), 98.3% ± 14.3 (CV = 14.6%), and 117.3% ± 12.0 (CV = 10.3%). Despite some difficulties to stabilize the two highest oxygen concentration tested, the three experimental groups were significantly different ($p < 0.001$).

During the course of the experiment temperature increased from 14°C to 18°C.

Growth and characteristics of fish

Survival was 100% during all the experiment.

No significant effect of oxygen level was observed on fish body weight all along the experiment (Fig. 1). At the end of the experiment, no significant difference in body weight or length ($p > 0.05$) of fish sampled was noticed (Tab. I). However fish reared at 117% oxygen saturation tended to be bigger (423 ± 73 g for the 117% group compared to 396 ±

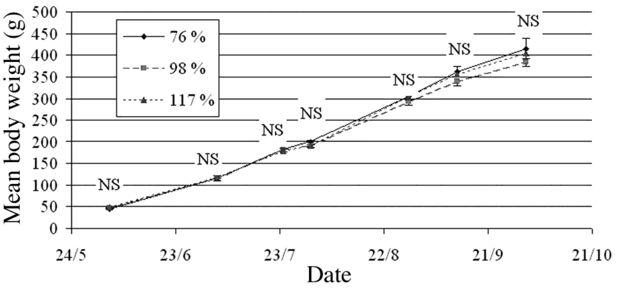

Figure 1. - Mean body weight of fish reared at 76%, 98% or 117% oxygen saturation during the experiment. Mean of 3 replicates ± standard deviation. NS: not significantly different ($p > 0.05$). *[Poids moyen des poissons élevés à 76%, 98% ou 117% de saturation en oxygène au cours de l'expérimentation. Moyenne de trois réplicats ± écart-type. NS : non significativement différent (p > 0,05).]*

Table I. - Effects of oxygen levels on morphometric traits and carcass indices at the end of the 18 weeks experiment. Mean ± standard deviation; n = 48 per treatment, values with the same letter in the same row are not significantly different ($p > 0.05$); Significant p value ($p < 0.05$) appeared with bold character; VSI: viscero-somatic index, HSI: hepato-somatic index. *[Effets des niveaux d'oxygène sur les caractères morphométriques et les indices des carcasses à la fin des 18 semaines d'expérience. Moyenne ± écart-type; n = 48 par traitement, les valeurs affectées de la même lettre dans la même ligne ne sont pas significativement différentes (p > 0,05) ; Les valeurs de probabilité p significative (p < 0,05) sont en caractère gras ; VSI : indice viscéro-somatique ; HSI : indice hépato-somatique.]*

Oxygen level		75.9 ± 4.0%	98.3 ± 14.3%	117.3 ± 12.0%	p
Body weight (g)		396 ± 68	395 ± 82	423 ± 73	0.12
Condition Factor K		1.44 ± 0.14	1.40 ± 0.12	1.44 ± 0.13	0.22
Height (mm)	Head	62.3 ± 4.1	62.2 ± 3.3	63.1 ± 3.1	0.36
	Dorsal	76.7 ± 6.2	75.8 ± 6.8	78.4 ± 6.1	0.12
	Caudal	26.4 ± 2.0	26.0 ± 2.3	26.8 ± 2.2	0.27
Width (mm)	Dorsal	37.7 ± 2.7	37.1 ± 3.6	38.0 ± 3.0	0.32
	Caudal	10.3^a ± 1.0	9.8^b ± 0.9	10.3^a ± 1.0	**0.02**
Carcass yield (%)		89.6 ± 1.3	89.6 ± 1.7	89.0 ± 1.7	0.15
VSI (%)		9.9 ± 1.0	10.1 ± 1.7	10.6 ± 1.6	0.09
HSI (%)		0.92 ± 0.11	0.96 ± 0.15	0.94 ± 0.13	0.44
Fat-meter value		2.61 ± 0.77	2.51 ± 0.68	2.68 ± 0.80	0.53

Table II. - Effects of oxygen levels on fillet yields (FY), dressed fillet yields (DFY), dressed and skinned fillet yields (DSFY) related to body weight at the end of the 18 weeks experiment, and FY, DFY and DSFY related to carcass weight (FYc, DFYc and DSFYc). Mean ± standard deviation; n = 24 per treatment, values with the same letter in the same row are not significantly different ($p > 0.05$); Significant p value ($p < 0.05$) appeared with bold character. *[Effets des niveaux d'oxygène sur les rendements en filets (FY pour "Fillet Yield"), en filets parés (DFY pour "Dressed Fillet Yield"), en filets parés et pelés (DSFY pour "dressed skinned fillet yields") rapporté au poids entier à la fin des 18 semaines d'expérience, et FY, DFY and DSFY rapporté au poids de carcasse (FYc, DFYc et DSFYc). Moyenne ± écart-type; n = 24 par traitement, les valeurs affectées de la même lettre dans la même ligne ne sont pas significativement différentes (p > 0,05) ; Les valeurs de probabilité p significative (p < 0,05) sont en caractère gras.]*

Oxygen level	75.9 ± 4.0%	98.3 ± 14.3%	117.3 ± 12.0%	p
FY (%)	62.5 ± 4.0	64.0 ± 4.3	64.6 ± 2.9	0.150
DFY (%)	54.4^b ± 4.0	56.3^{ab} ± 3.6	57.2^a ± 2.4	**0.017**
DSFY(%)	48.7^b ± 4.2	50.7^a ± 3.4	51.3^a ± 2.4	**0.023**
FYc (%)	69.9 ± 4.2	71.4 ± 4.5	72.7 ± 3.0	0.057
DFYc (%)	60.8^b ± 4.1	62.8^a ± 3.8	64.3^a ± 2.2	**0.003**
DSFYc (%)	54.4^b ± 4.5	56.6^a ± 3.6	57.7^a ± 2.3	**0.006**

68 g for the 76% one). No difference in morphometric traits (condition factor K, body height or dorsal width) was observed between treatments except a lower caudal width for fish reared at 98% oxygen level compared to the two other groups ($p < 0.05$, Tab. I). No significant difference in fat-meter values was measured.

Yields

No significant effect of oxygen level was measured on carcass yield, viscero-somatic index, nor on hepato-somatic index (Tab. I). However, oxygen level had a significant positive effect on final fillet yields (dressed skinned fillet: DSFY). When comparing 76 and 117% oxygen saturation, an increase of 2.6% and 3.3% for fillet yield expressed as percent of body weight or carcass weight, respectively, was observed (Tab. II). The most significant effect was measured for the dressed fillet yield (DFY) which was 2.8% higher in the 117% group than in the 76% one ($p = 0.017$). No significant effect was obtained for the raw fillet yield (FY, + 2.1% for the 117% group compared to the 76% one, $p = 0.15$), and no more positive additive effect was observed after skin removal (DSFY, + 2.6% for the 117% group compared to the 76% one, $p = 0.023$).

Red muscle width

Figure 2 shows red muscle, which forms a characteristic V-shape at the level of the lateral line, under the skin coloured in red because of its high collagen content. Deeper in the musculature, white muscle is anatomically separated from red muscle by a sheet of connective tissue. The mean values of red muscle width and red muscle proportion in terms of body width were not significantly different at 76% and 98% oxygen saturation (Tab. III). However, fish reared at 117% oxygen saturation had a higher absolute mean red muscle width (2.52 mm compared to 2.13 mm and 1.97 mm for the 76% and 98% groups, respectively, $p < 0.001$) and a higher proportion of red muscle (49.8% compared to 41.4% and 41.3% for the 76% and 98% groups, respectively, $p < 0.001$) than their 76% and 98% counterparts.

DISCUSSION

Fish growth and carcass quality parameters

If oxygen levels, ranging from 50 to 180% of saturation, have been shown to have a significant positive effect in 2 g rainbow trout growth (Dabrowski *et al.*, 2004), in general, no effect was observed on rainbow trout growth when oxygen concentration fluctuate around saturation (± 20%) (Edsall and Smith, 1990; Doulos and Kindschi, 1990; Caldwell and Hinshaw, 1994). These results are consistent with ours, as after a 18 weeks exposure to 76-117% oxygen saturation, no significant effect on growth of 50 g to 400 g trout was observed, even though the growth rate was high.

Some rearing parameters, such as starvation or exercise, have been shown to affect fish morphology and carcass traits (Bugeon *et al.*, 2003). To our knowledge, no data is available on a putative effect of oxygen level during rearing on fish carcass quality. This study showed a very slight impact of the three oxygen levels tested for 18 weeks on fish morphometric and carcass traits. A significant effect was observed on viscera weight ($p < 0.01$) and a tendency on viscerosomatic index ($p < 0.1$), with the highest values for fish reared at 117% oxygen level despite no significant difference in fish body weight. This result may be due to higher adipose tissue deposition around the viscera, possibly related to difference in feed intake, but such an effect of oxygen has never been described. Lipid content, estimated by fat meter, did not differ between groups, suggesting that oxygen level may affect perivisceral adipose tissue without affecting the intramuscular lipid content and more generally, that the location of fat deposits may be affected independently by different rearing conditions.

Fillet yields and proportion of muscle types

Many studies have reported the importance of ambient oxygen on muscle tissue in mammals (for review see Clanton and Klawitter, 2001, and Hoppeler and Vogt, 2001) but the effect of oxygen is also related to differences in muscle activity or pathological conditions. Some in vitro studies with primary muscle cell culture have also shown the importance of oxygen on muscle cell proliferation and differentiation (Csete *et al.*, 2001; Kubis *et al.*, 2005). All these studies demonstrated that hypoxia and/or hyperoxia has some effects on muscle biochemistry and metabolism but no in vivo effect on muscle mass has been mentioned.

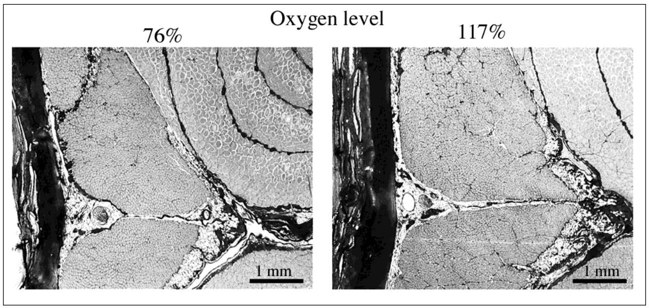

Figure 2. - Example of histological sections of muscle samples taken at the level of the adipose fin, stained with “Rojkind” dye. *[Exemple de coupes histologiques d’échantillons de muscle prélevés à l’aplomb de la nageoire adipeuse, colorées avec le colorant de “Rojkind”.]*

In fish, some studies have also demonstrated an effect of oxygen on characteristics of muscle tissue. Indeed, in 200-400 g rainbow trout, acute hypoxia brings about a significant decrease in energy stores (PCr, ATP) in red muscle but not in white muscle (van Raaij *et al.*, 1994). Recently, a proteomic study with zebrafish (*Danio rerio*) showed that acute hypoxia did not change the general pattern of protein expression but affected the amounts of some low abundance proteins (6 out of 400 spots analysed) which were not identified (Bosworth *et al.*, 2005). However no data are available on the quantity of muscle tissue in relation to oxygen level.

In our study, the highest oxygen level tested showed a significant positive effect on fillet yields, and the differences between groups were higher for yields related to carcass weight, as carcass yield tended to be lower for groups reared at the highest oxygen level (117%). Difference in fillet yields could not be related to different ability of fish to be filleted between groups (Fauconneau *et al.*, 1995) as no difference in fish morphology was measured, except a lower caudal width at 98% oxygen saturation that was not correlated to fillet yield. The higher fillet yield measured for the 117% oxygen saturation group may be related to a higher muscle mass for this group as no difference was observed in dressing losses between groups.

As we studied a long-time effect of oxygen levels, potentially leading to an adaptive phenomenon, it seems likely that the long-term disposable oxygen level in water may orientate muscle fibre metabolism and favour the relative development of glycolytic (white) or oxidative (red) muscle. Our study showed a significant positive effect of oxygen level on the proportion of red muscle but the biological basis remains to be elucidated. The higher fillet yield measured at high oxygen levels could be due to a higher quantity of red muscle, as an adaptive phenomenon to oxygen availability. The measurement of red muscle width in one position along fish body axis does not give a precise overall relative quantification of the two muscle types. So, further studies would be needed to check an effect on red muscle development throughout the length of the fish body, and quantify if this increase in red muscle mass explain the higher fillet content. Other rearing factors such as water temperature or exercise have been shown to affect the proportions of red and white muscle (Johnston and Lucking, 1978; Davison, 1989).

Table III. - Effects of oxygen levels on red muscle (RM) width and the proportion of red muscle in the body width at the level of the adipose fin. Mean ± standard deviation, n ≥ 20 per treatment, values with the same letter in the same row are not significantly different ($p > 0.05$); Significant p value ($p < 0.05$) appeared with bold character. *[Effets des niveaux d’oxygène sur l’épaisseur de muscle rouge (RM pour “Red Muscle”) et proportion de muscle rouge dans l’épaisseur du poisson au niveau de la nageoire adipeuse. Moyenne ± écart-type; n ≥ 20 par traitement, les valeurs affectées de la même lettre dans la même ligne ne sont pas significativement différentes (p > 0,05)) ; Les valeurs de probabilité p significative (p < 0,05) sont en caractère gras.]*

Oxygen level	75.9 ± 4.0%	98.3 ± 14.3%	117.3 ± 12.0%	p
RM maximal width (mm)	$2.13^b \pm 0.40$	$1.97^b \pm 0.40$	$2.52^a \pm 0.51$	**< 0.001**
RM width proportion (%)	$41.4^b \pm 8.2$	$41.3^b \pm 7.3$	$49.8^a \pm 11.0$	**< 0.001**

CONCLUSION

Management of adequate oxygen levels is an especially important rearing factor in salmonid farming. This work showed that increasing rearing oxygen level can increase the proportion of red muscle in muscle mass. However, further work is necessary to understand the biological mechanisms underlying this greater red muscle development.

Nevertheless, we demonstrated that small differences in oxygen levels, which have no impact on fish growth and morphology, may affect fish carcass quality with an economic impact for salmonid producers.

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